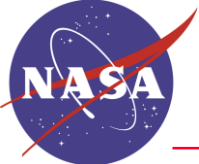


LCRD Optical Ground Station 1

W. T. Roberts and S. Piazzolla

Jet Propulsion Laboratory, The California Institute of Technology

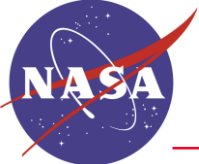


Laser Communications Relay Demonstration (LCRD)

Jet Propulsion Laboratory
California Institute of Technology

- **Optical Ground Station 1 (OGS1)** is being developed to support the LCRD project
- **Capable of sustained bi-directional communications**
 - Up to 1.24 Gbps – DPSK
 - Up to 311 Mbps – PPM
- **LCRD Objectives**
 - Demonstrate bi-directional optical communications
 - Characterize system performance over a variety of conditions
 - Transfer optical communication technology to industry
 - Support, test and demonstrate optical communication standards
 - Demonstrate extensive multi-user networking
 - Demonstrate effectiveness of adaptive optics for communication links

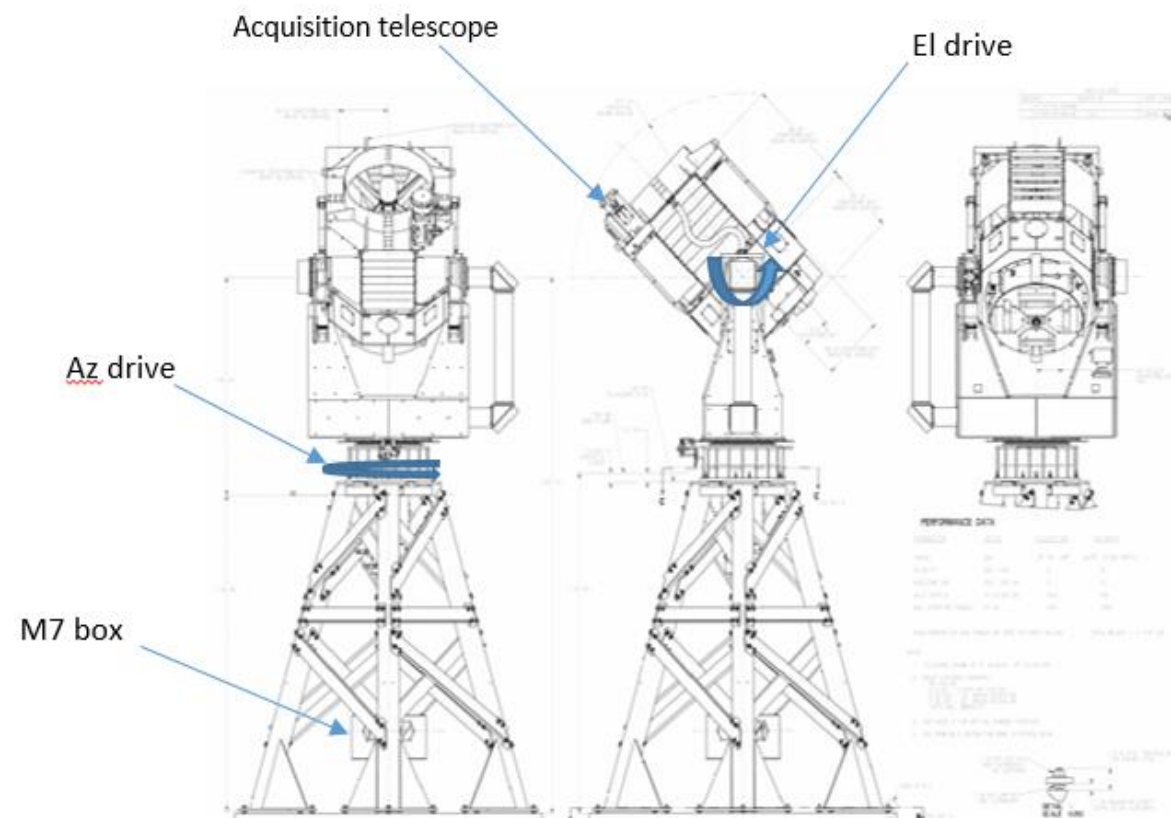




OCTL Telescope

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California Institute of Technology

- 1-meter F/76 telescope in coudé configuration
- Fast-slewing EI over Az mount for satellite tracking
- 4 coudé ports allow concurrent experiments
- Designed for daytime operations





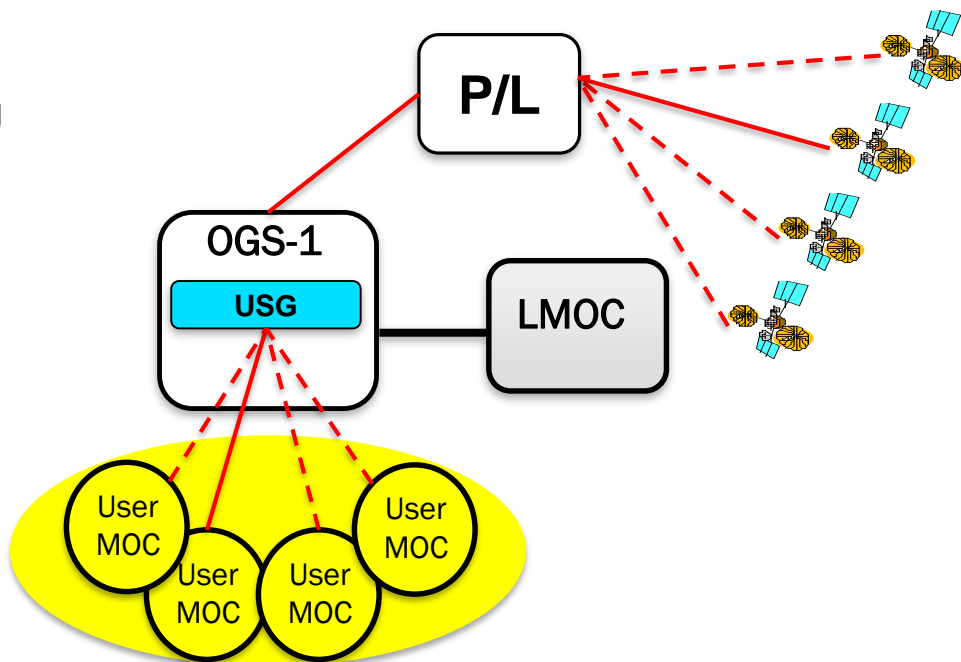
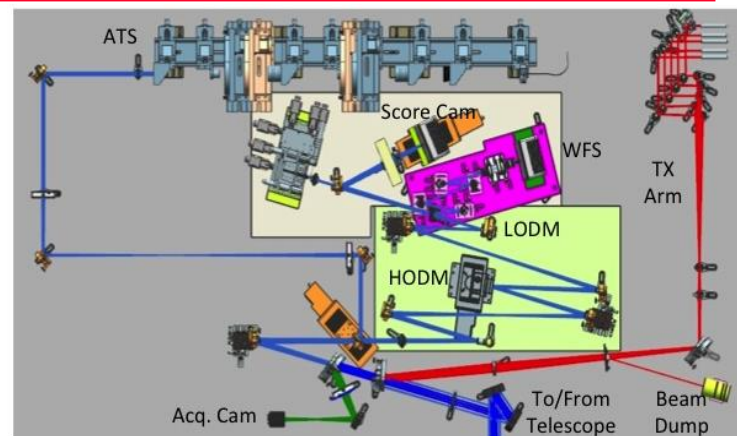
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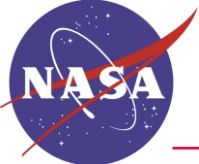
Unique Features of OGS-1

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- **Fast Adaptive Optical system**
 - Two deformable mirrors to compensate for large stroke and high spatial frequency
 - 10 kHz wavefront sensor
 - Scoring camera for evaluation of corrected Strehl ratio
- **High bandwidth networking services**
 - Up to 12 simultaneous users connecting through User Services Gateway
 - Four service types
 - SymbolStream
 - BitStream
 - AOS
 - Tunnelled IP
 - Supports virtual channels
 - Supports simultaneous guest users
 - High bandwidth platform and MOC simulators
 - Schedule-driven services



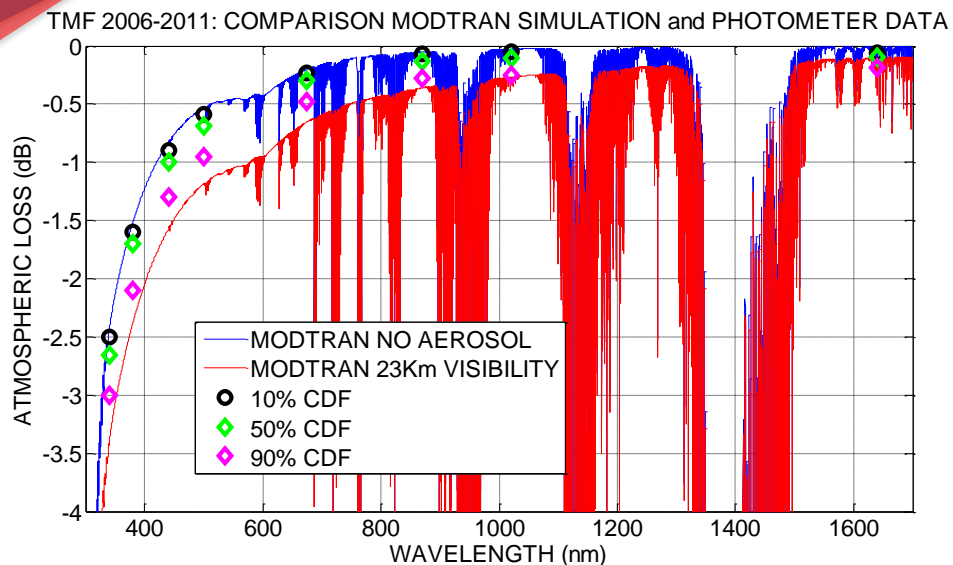
Simulated by User MOC Simulator



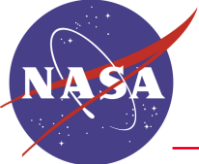
OGS-1 Loop-Back Link

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- Loop-back link is best measure of ground station performance
- Calculation of LCRD Link:
 - Calculate uplink/downlink operating points
 - Photons/bit at receivers
 - Evaluate signal fade statistics
 - Calculate edge-to-edge curves
 - Evaluate uplink/downlink margins



Atmospheric Transmission at OGS-1

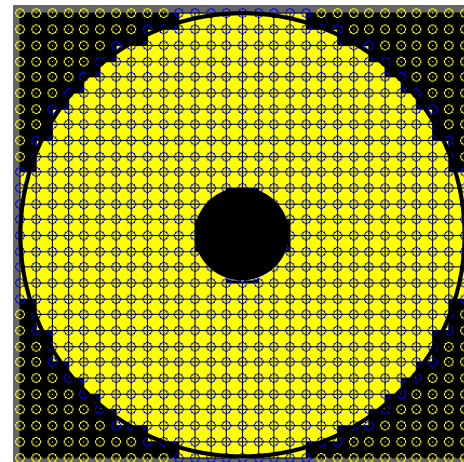


OGS-1 Wave Optics Simulation

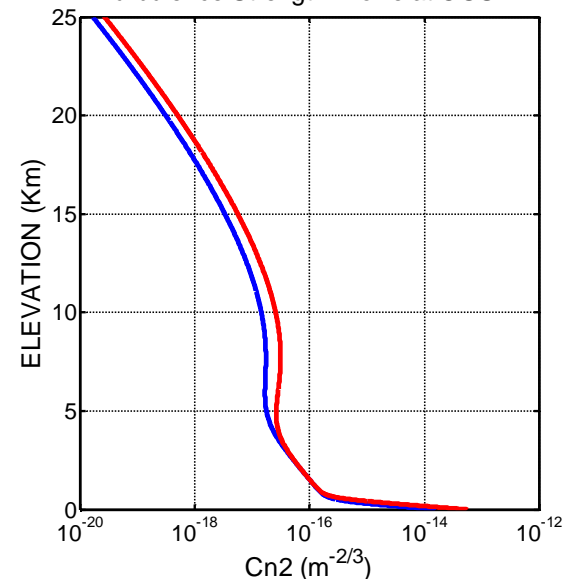
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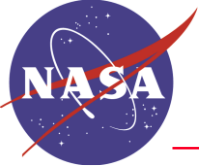
- We use a wave-optics simulation to determine fading statistics on uplink/downlink beams
- We use nominal and worst case conditions in the simulation
 - Hufnagel-Valley profile with ground layer at OGS-1
 - 5-layer atmosphere assumed
 - Turbulence conditions at 500 nm at zenith
 - Nominal case $r_0=5.2$ cm
 - Worst case $r_0=2.7$ cm
 - Uplink beam divergence: $\theta=20$ μ rad full-angle
 - Wind speed of 2.84 m/sec (nominal)
 - 5.6 m/sec (worst case)
 - Beam elevation angle from OGS-1 of 45 degrees
- OGS-1 AO modeled as 28x28 sub-apertures
 - Wavefront sensor update rate of 10 kHz
- Simulation results
 - Time series of uplink signal at flight terminal
 - Time series of downlink signal corrected by AO coupled to the Ground Modem single-mode fiber

OGS-1 Sub-Aperture Geometry



Turbulence Strength Profile at OGS-1

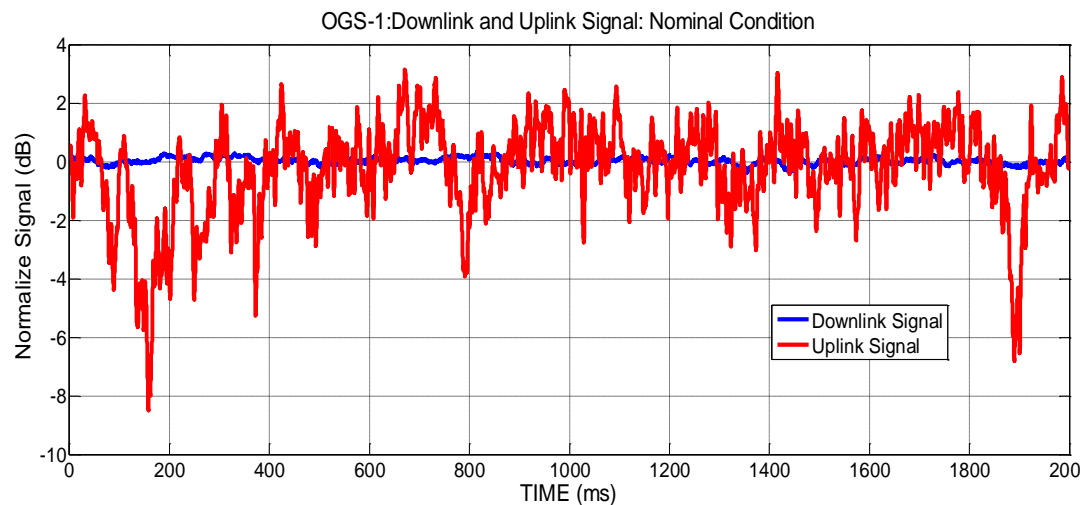
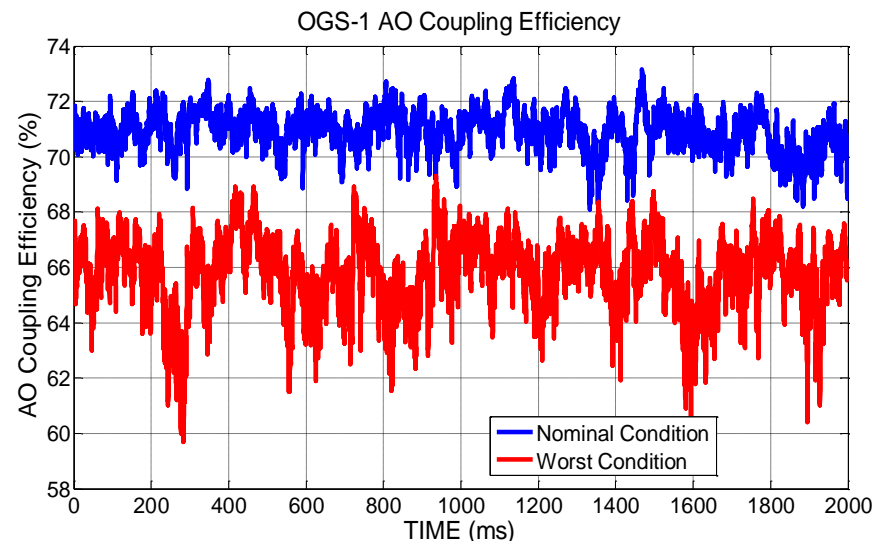


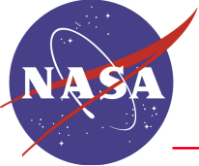


OGS-1 Loop Back Results

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- Our Adaptive Optics is expected to couple 70% of the downlink signal into the Modem SMF under nominal conditions
 - 65% coupling efficiency or better 90% of links
 - Minimum 55% coupling required
- Downlink fading is averaged over large (1-m) aperture
 - $\sigma_i^2 = 7 \times 10^{-4}$ under nominal conditions
- Uplink fades are much worse
 - $\sigma_i^2 = 0.09$ under nominal conditions
 - $\sigma_i^2 = 0.29$ under worst-case (90%) conditions
- Time series from wave-optics simulation are shown
 - Used to derived edge-to-edge curves
 - PPM
 - DPSK

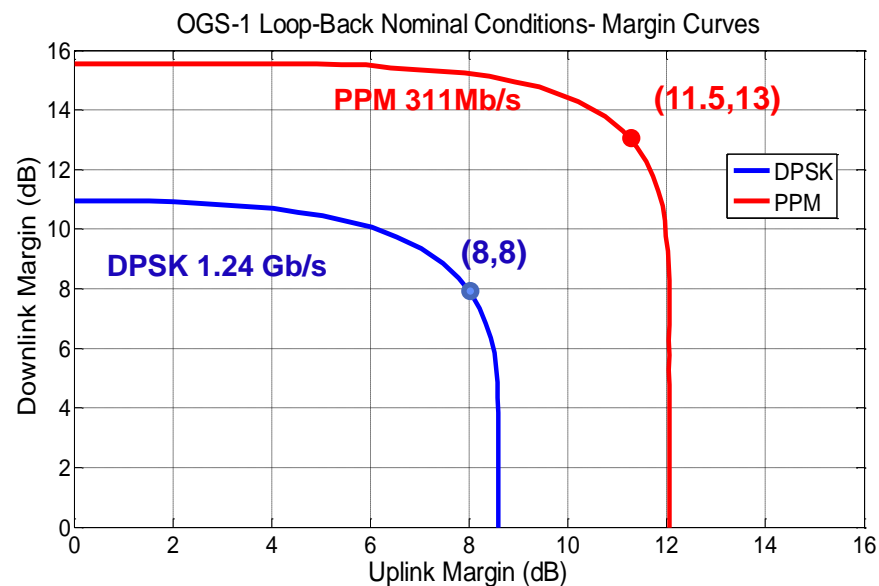
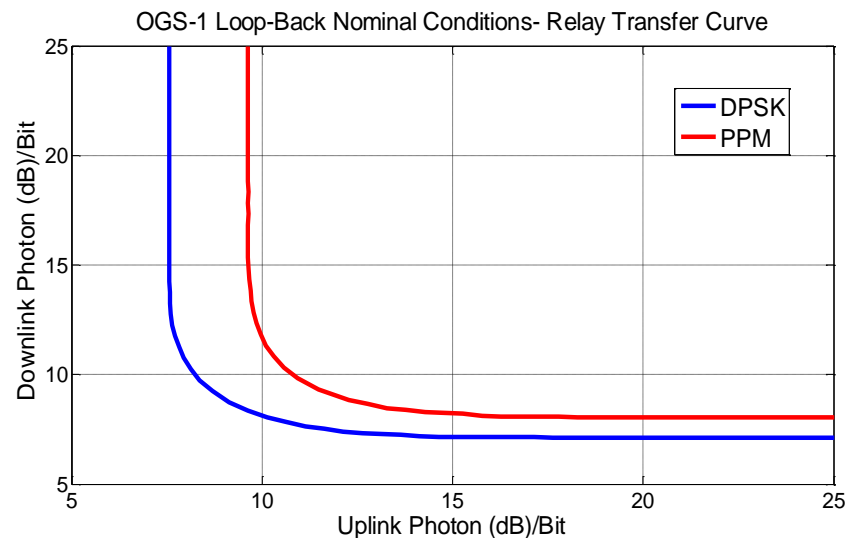


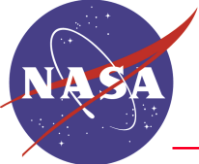


OGS-1 Loop Back Link Margin

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- The relay transfer curves represent the locus of points at up/down receivers where the margin is 0 dB for given photon/bit flux
 - Lower photon flux at one end may be compensated by higher flux at other end
 - Included up/down fading statistics
 - Interleaver of 0.87 sec
 - DVB-S2 coding, code rate $R=0.5$
 - Required code word error rate 10^{-4}
- DPSK more efficient than PPM
- Margins derived from relay transfer curve
 - Based on operating point
 - 10 W uplink transmit power
 - 0.5 W downlink transmit power
- Lower data rate of PPM provides more margin
- OGS-1 expected to have plenty of operating margin for DPSK and PPM links under nominal conditions

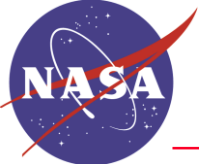




OGS-1 Loop Back Summary

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- **OGS1 is in development to support LCRD**
 - Characterizes performance over range of atmospheric conditions
 - Supports high-bandwidth networking services
- **Supports different signaling modulations**
 - DPSK to demonstrate high-bandwidth links
 - PPM to demonstrate deep-space networking links
- **Loop-back demonstration characterizes ground station performance**
 - Wave optics simulation to calculate fade statistics
 - Incorporates predicted performance of AO System
 - Incorporates site-specific conditions
- **Maximum rate links predicted to have range of viable operating points under nominal conditions**
 - ~ 8 dB of symmetrical DPSK margin
 - ~12 dB of PPM margin
- **We anticipate excellent performance of OGS-1 with LCRD**



Acknowledgements

Jet Propulsion Laboratory
California Institute of Technology

- **Supporting Development**
 - **Mr. Arivid Croonquist – System Engineer**
 - **Dr. Lewis C. Roberts – Integrated Optical System Lead**
 - **Mr. Vachik Garkanian – Telescope Lead**
 - **Mr. Thang Trinh – Monitor and Control Lead**
 - **Dr. Malcolm W. Wright – Beacon Laser Lead**
 - **Dr. Ryan Rogalin – Ground Modem, Codec, Amplifier Interface**
 - **Ms. Janet P. Wu – Laser Safety Lead**
 - **Dr. William Walsh – Networking Lead**
 - **Dr. Dimitrios Antsos: Program Management**
- **Sponsorship**
 - **Dr. Don Cornwell - NASA SCan**